SECURITY CLASSIFICATION OF THIS PAGE

AD-A274 251

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

DTIC ELECTE DEC 3 0 1993 S A

(2)

	1b. RESTRICTIVE MARKINGS
	3. DISTRIBUTION/AVAILABILITY OF REPORT APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR-
6a. NAME OF PERFORMING ORGANIZATION DEPARTMENT OF PSYCHOLOGY STANFORD UNIVERSITY 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AIR FORCE OFFICE OF SCIENTIFIC RESEARCH (NL)
6c. ADDRESS (City, State, and ZIP Code) BUILDING 420, JORDAN HALL STANFORD, CA 94305-2130	7b. ADDRESS (City, State, and ZIP Code) BOLLING AIR FORCE BASE, DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR 8b. OFFICE SYMBOL (If applicable) NL	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-89-0076
8c. ADDRESS (City, State, and ZIP Code) BUILDING 410 BOLLING AIR FORCE BASE, DC 20332-6448	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61102F PROJECT NO. 2313 TASK NO. A4 WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

INDUCED PICTORIAL REPRESENTATIONS (UNCLASSIFIED)

12. PERSONAL AUTHOR(S)

TVERSKY, BARBARA G.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL TECHNICAL	FROM 11/01/88 TO 02/28/94	November 30, 1993	30

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	mental models, visual cognition, mental maps, discourse processing, spatial language
05	09		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Language is often used to describe environments or to give directions. This project has investigated how spatial language describing large and small scale environments is comprehended and produced. The research on large scale environments, such as a town, has shown that in descriptions, people adopt either a route or a survey perspective or a mixture of both. In comprehension of such descriptions, people form spatial mental models that are more abstract than either perspective. The research on small scale environments has investigated people's mental models of the objects surrounding them. People are faster to access objects at some directions from their bodies than others. Accessibility depends on enduring characteristics of the perceptual world and the relation of the body to it. Several variations and extensions of each project are described. The research has implications for spatial cognition as well as language comprehension and production.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
JOHN F. TANGNEY, PH.D.	(202) 767-5021	NL

DD Form 1473, JUN 86 Previous editions are obsolete. SECURITY CLASSIFICATION OF THIS PAGE

8 DEC 1993 2130

Final Technical Report: 1993

AFOSR-89-0076

Induced Pictorial Representations

Summary. Language is often used to describe environments or to give directions. This project has investigated how spatial language describing large and small scale environments is comprehended and produced. The research on large scale environments, such as a town, has shown that in descriptions, people adopt either a route or a survey perspective or a mixture of both. In comprehension of such descriptions, people form spatial mental models that are more abstract than either perspective. The research on small scale environments has investigated people's mental models of the objects surrounding them. People are faster to access objects at some directions from their bodies than others. Accessibility depends on enduring characteristics of the perceptual world and the relation of the body to it. Several variations and extensions of each project are described. The research has implications for spatial cognition as well as language comprehension and production.

1 Introduction.

There are many situations in which we have no choice but to explain things in words rather than show them. Although not perfect, language often serves such purposes quite well. One of those situations is describing environments, whether we are telling a new friend about the neighborhood where we grew up, or an old friend about our recent trip to Europe, or a stranger how to find their way to the campus bookstore. Novels, tourist guides, and history and science texts abound in spatial descriptions. A number of years ago, we began exploring the nature of spatial mental representations produced by words alone (Tversky, 1991b, in press, b).

Languages are rich in spatial vocabulary probably because space is so important to every aspect of our lives (e. g., Tversky and Clark, 1993). Spatial language has been co-opted for other, metaphoric uses that pervade speech. We change *perspectives* and enter new *fields*, careful not to encroach on another's *space*. Many of the same cognitively natural conventions that underlie the use of spatial language also underlie the use of space in graphic representations (Tversky, in press a, in press b; Tversky, Kugelmass, and Winter, 1991). Some spatial information seems easily conveyed by language, and other information less so. Those terms that have proved their usefulness by being old and frequent and metaphorically extended are the ones that should communicate effectively. A notable example is the terms that describe spatial relations, such as *front, back, left, right, above, below,* and *north, south, east,* and *west.* Part of the communicative effectiveness of these terms is shared knowledge about the appearances of environments. Other spatial information seems more difficult to convey, for example, precise information about distance and angle. Conveying distance and angle requires recently developed technical language that most of us do not use frequently enough to become accurate. Distance information that relies on shared knowledge about stereotyped units, such as rooms or blocks in American culture, should be better conveyed and understood than metric information.

Our own work has investigated communication of spatial relations for large scale and small scale environments. The work of Johnson-Laird and his collaborators (Ehrlich and Johnson-Laird, 1982; Mani and Johnson-Laird, 1982), of Glenberg, Meyer and Lindem (1987) and of Perrig and Kintsch (1985) encouraged us in this endeavor. We were also encouraged by the related work of Morrow, Greenspan, and Bower (1987) and Morrow, Bower, and Greenspan (1989) showing that stereotypic distance units may be reflected in sentence comprehension time. Globally, we have been interested in the nature of the mental representations that readers construct from descriptions, and have used reaction time and accuracy measures as reflections of the mental representations. The project has taken us into a number of other issues as well, including perspective and perspective-switching, the nature of spatial descriptions, and the comparison of environments learned by description to those learned by perception. I will begin with the work on large-scale environments.

2 Comprehending Route and Survey Descriptions of Large-scale Environments.

2.1 Introduction. An informal survey of tourist guides revealed that tourist sites seem to be described from one of two perspectives, survey or route. In a *survey* perspective, descriptions take a view from above the environment and describe the locations of landmarks relative to one another in terms of north, south, east, and west. In a *route* perspective, descriptions take a view from within the environment, and take addressees on a mental tour of the environment describing the locations of landmarks relative to the changing position of the addressee in terms of the addressee's front, back, left, and right. These two perspectives correspond to the two major ways of learning about environments, from maps and from navigation. The route perspective corresponds to what linguists have called a *deictic* perspective and the survey perspective corresponds to what linguists have called an *extrinsic* perspective (Fillmore, 1975; Miller and Johnson-Laird, 1976).

Taylor and Tversky (1992b) wondered whether the two perspectives led to different mental representations, that is, whether perspective is encoded in the spatial mental representations of the described environments. Previous work on descriptions and on learning environments suggested that perspective would be encoded in the mental representations of environments. Readers remember information associated with the narrative perspective better than information associated with an alternative perspective (Abelson, 1975; Anderson and Pichert, 1978; Bly, 1989; Bower, 1978). Some aspects of environments, such as relative directions, are better acquired or more accessible from studying maps, and other aspects of environments, such as travel distance, are better acquired from navigation (Evans and Pezdek, 1980; Sholl, 1987; Streeter, Vitello, and Wonsiewicz, 1985; Thorndyke, 1981; Thorndyke and Hayes-Roth, 1982). The research on which our own was fashioned, experiments by Perrig and Kintsch (1985), also found differences due to perspective.

2.2 Design. We first designed four environments, varying in scale, each with about a dozen landmarks. The largest environment was a county-sized recreation area and the next largest was a small town. The two smaller-scale environments were a zoo and a convention center. For each environment, we wrote two descriptions, one from a route perspective and one from a survey perspective. Each description contained information locating the landmarks in the environment according to the appropriate perspective. To make the descriptions more interesting and realistic, each also contained identical non-locative information, for example, describing activities that took place at the landmarks. We pretested the descriptions to make sure that they were equally coherent and that each allowed readers to accurately place all the landmarks. In four experiments, subjects studied a route or a survey description of an environment, followed by a number of tests of memory. First, subjects verified true-false statements, both locative and non-locative, from the descriptions. The locative statements were either verbatim from one of the texts, route or survey, or were inference statements from one of the two perspectives. The inference statements contained information that could be inferred from information in the descriptions, but had not been explicitly stated in either description. Following the verification of statements, subjects drew a map of the environment.

2.3 Results. From reading either narrative perspective, subjects drew highly accurate maps of the environments, indicating that they formed good spatial mental representations from the descriptions. If perspective is encoded in the spatial mental representations formed from the descriptions, then responses to inference statements from the same perspective as the narrative should be faster and more accurate than to inference statements from the other perspective. However, this failed to happen in four experiments, including an experiment where subjects read only a single description and did not know they would be asked to draw maps. This is evidence that perspective is not encoded in the spatial mental models formed from these types of descriptions. Subjects were faster and more accurate to verbatim statements than to inference statements. Altogether, survey and route perspectives were equally effective in conveying information about the environments.

2.4 Interpretation. Readers seemed to have formed at least two mental representations of the descriptions. First, they formed a representation of the language of the description that allowed them to respond faster and more accurately to the verbatim statements than to the inference statements. Second, they formed a representation of the situation described by the text, what we have called (after Johnson-Laird, 1983) a spatial mental model, that allowed them to draw accurate maps of the environments and to respond to the inference statements.

The spatial mental models subjects formed of the described environments were apparently indifferent to perspective. They allowed subjects to respond as quickly and accurately to statements in the same perspective that they had read and in the other perspective, for both perspectives. This suggests that the spatial mental models contained information about the spatial relations among landmarks in a perspective-free fashion, allowing the taking of either perspective with equal ease. As such, spatial mental models are similar to structural descriptions, common in computer models of object recognition, and to architect's models of buildings. Each incorporates the spatial relations among parts and allows the taking of many perspectives.

2.5 Caveats and Qualifications. We do not mean to claim that all spatial mental representations of environments, whether learned from descriptions or learned from experience, have this character. These experiments were done under ideal conditions. The environments and the descriptions were carefully composed, the memory load was light, the time given for learning was ample. If these conditions are not met, then there is no reason to expect that subjects will form coherent and complete mental representations of the spatial relations that are perspective free. In fact, many experiments have demonstrated just that, that people's mental representations of environments are often incoherent and incomplete and from a particular perspective (Schiano and Tversky, 1992; Tversky, 1991a, 1992a, 1992b, 1993). It is important to know that this need not be the case. But it is also important to remember that excellent as they were, the spatial mental models subjects formed did not contain metric information, only categorical spatial relations. The descriptions did not relay metric information, and we do not think that precise metric information is easy to relay accurately.

3 Producing Descriptions of Large-Scale Environments.

3.1 Introduction. After completing this research, we wondered what perspectives people actually took in describing environments. Our own descriptions had been carefully and self-consciously fashioned, so we wanted to know how laypeople spontaneously constructed descriptions. There was a widespread belief in the psycholinguistics literature that people ordinarily give route descriptions of environments (cf. Levelt, 1982). This belief came primarily from a well-known study of descriptions of New York City apartments by Linde and Labov (1975). In that study, the overwhelming majority of descriptions took listeners on a mental tour of the environment. More recent work by Ehrich and Koster (1983), Levelt (1982), and Ullmer-Ehrich (1982) strengthened that conclusion. The conclusion was justified by an analysis of Levelt's (1989), in which he pointed out that space is multidimensional but speech is linear. Because a route is similar to exploration of an environment, it provides a natural way to linearize space. Survey perspectives are also natural ways of conceptualizing environments. People get survey perspectives from heights, and throughout time, cultures have repeatedly invented and used maps, which give survey perspectives.

3.2 Investigating a Greater Variety of Environments. Altogether, the range of environments studied thus far seemed too narrow to come to any definite conclusions about perspective. We embarked on a mirror-image of our first set of tasks (Taylor and Tversky, 1992a; Taylor and Tversky, 1993). We constructed maps of the recreation area and convention center from our previous work, and added to that a map of an amusement park. Subjects studied one of these maps. Later, they wrote descriptions of the environments from memory. Their descriptions were coherent and accurate, allowing a naive group of subjects to place nearly all the landmarks correctly.

Subjects produced survey, route, and a mixture of survey and route descriptions, with the majority of the descriptions mixed, followed by survey, followed by route. The town received mainly survey and mixed perspective descriptions, with very few route descriptions, and the convention center received mainly route and mixed perspective descriptions, with very few survey descriptions. This suggested that characteristics of the environment determined the perspective chosen. These findings corroborate the results of the previous set of studies. They suggest that perspective is not inherent in people's mental representations of environments. Selection of a description perspective, then, has to do with how convenient it is to describe that environment with that perspective. Convenience of perspective seems to depend at least in part on characteristics of the environments themselves.

The town and the convention center were described with different perspectives and differed on a number of environmental characteristics that might be relevant to perspective. The town was an open environment, whereas the convention center was enclosed; the town was relatively large scale, and the convention center was small scale; the town had landmarks on several size scales, mountains, river, roads, and buildings, and the convention center had landmarks on a single size scale, rooms; the town had more than one possible route and the convention center had only a single route.

3.3 Varying Environmental Characteristics. In the next experiment (Taylor and Tversky, 1993), we tested the hypothesis that characteristics of the environment affect perspective choice by systematically varying the environments on a number of features that differentiated the town and the convention center, and that might be related to choice of perspective. Subjects wrote descriptions of four of 16 environments from memory. Forty-five percent of the descriptions had a survey perspective, 34% had a mixed perspective, and 21% had a route perspective. Two of the environmental variables had no effect on choice of perspective: whether the environment was open or enclosed, and whether the environment was large scale or smaller scale.

Two other variables did affect the selection of a perspective. There were fewer mixed and more route descriptions when the environments had only a single path and when the landmarks were on the same size scale. This makes sense in terms of the pragmatics of constructing a coherent description. It is easier to construct a route through an environment when the environment has only one path than when the environment has many possible paths through it. The presence of landmarks on the same size scale makes it more likely that each landmark will be described in terms of the adjacent landmark. When one or more landmarks are larger and more salient, then it is more likely that smaller scale landmarks will be described with respect to the large scale landmark. If many landmarks are described with respect to a single salient one, it seems easier to differentiate them by their canonical directions from the large landmark than by taking a tour around the large landmark.

3.4 Varying Acquisition Characteristics. Another difference between our studies and the previous work is that in our studies, subjects learned the environments by studying maps, whereas in some of the previous work, subjects had learned the environments by navigating them. Linde and Labov's subjects described apartments they had lived in and presumably walked around in quite a bit. Studying a map might encourage a survey perspective whereas navigation might encourage a route perspective. Acquisition conditions can only explain part of the results, however. Levelt's (1982) subjects described a map of a network of colored dots, and produced route descriptions.

We ran a small study where we asked students to describe environments that they presumably experienced primarily by navigation rather than maps, two areas on campus and their neighborhoods at home. The descriptions were not as detailed or coherent or accurate as the descriptions of the memorized maps. Most of them would not have allowed a naive subject to correctly place most of the landmarks. In this study, the majority of the descriptions were route descriptions, in contrast to our previous studies. However, subjects did produce survey and mixed perspective descriptions of environments they had experienced primarily or only by navigation.

3.5 Determinants of Description Perspective. Selection of perspective to describe an environment is clearly affected by characteristics of the environment, but it may also be affected by acquisition conditions.

4 Small Scale Environments: Spatial Frameworks.

4.1 Introduction. The experiments on descriptions of large scale environments showed that under ideal circumstances, people can form spatial mental representations of environments that are coherent, complete, and perspective free. Responding to particular questions, however, required taking a specific perspective on the environment. We turn now to discuss experiments investigating responding to a specific perspective, namely that of an observer in a scene. At the same time, we switch from large scale to small scale environments. We also switch referents of the term "we." Here, "we" refers initially to Franklin and Tversky, and later includes Bryant as well.

4.2 Task. The situation Franklin and I (Franklin and Tversky, 1990) chose to study is one that people find themselves in most of the time, in a setting, surrounded by objects. We were interested in the simplest variant of that scene, keeping track of the positions of objects under the simplest form of navigation, turning in place. It is a task that people seem to do effortlessly. In order to study it, we wrote narratives describing "you," the observer and reader, in a setting such as a barn, with objects such as a lantern, a pail, a rake, and a saddle located beyond "your" head, feet, front, back, left, and right. Subjects studied the narratives until they knew them well, and then turned to a computer that oriented them toward one of the objects, and queried them for the objects located in each of the six directions beyond the body. When all locations had been probed, the computer again reoriented the reader, and again queried the reader for the objects now located in the six directions beyond the body. Performance was essentially error-free, so the data of interest are the reaction times to each of the six directions.

4.3 Equiavailability and Mental Transformation Accounts don't Work. How might someone in this situation perform the task? We considered three possible theories. According to the first theory, the *equiavailability* theory, all directions in space are in principle equally salient and available, much like viewing a picture, where certain objects in the picture may attract attention more than others, but not because of the direction per se. Equiavailability predicts equal reaction times to all directions. The second theory extends the research in mental imagery (for reviews, see Finke and Shepard, 1986; Kosslyn, 1980) from the typical two-dimensional setting to the current three-dimensional setting. According to a *mental transformation* account, readers would imagine the scene and themselves in it. To verify the object in a given direction, readers would imagine themselves turning to inspect that direction. This theory predicts that times should be fastest to front, next fastest to directions 90 degrees from front, that is, left, right, head, and feet, and slowest to back, which is displaced 180 degrees and requires the longest mental transformation. The data of the first five experiments, and by now, many more, reject both the equiavailability and mental transformation theories as accounts for the standard situation (something like the equiavailability account seems to hold for certain complex situations, see Franklin, Tversky and Coon, 1992).

4.4 Spatial Framework Theory: Upright Case. The theory that accounts for the data is the *Spatial Framework Theory*. This theory is based on analyses of language and space by Clark (1973), Fillmore (1975), Levelt (1984), Miller and Johnson-Laird (1976), and Shepard and Hurwitz (1984), but it is different from any of the previous analyses. According to it, readers construct a mental spatial framework from extensions of the body axes, and associate objects to the appropriate axes. Readers update the observer's positions as the observer is reoriented. The three axes vary in accessibility depending on characteristics of the body, characteristics of the perceptual world, and the posture of the body. For the upright observer, the most salient and accessible axis is the head/feet axis. This is because it is an asymmetric axis of the body and it correlates with the only constant asymmetric axis of the perceptual world, the up-down axis induced by gravity. The next most accessible axis is the front/back axis, which has perceptual and functional asymmetries, and the least accessible axis is the left/right axis, which has no salient asymmetries. The pattern of reaction times in the four upright experiments of Franklin and Tversky (1990) and of subsequent experiments conformed to this pattern, fastest reaction times to head/feet, then front/back, then left/right.

4.5 Spatial Framework Theory: Reclining Case. When the observer reclines and reorients by turning onto the front, back, left, and right sides, the situation changes. Gravity no longer corresponds to any major axis of the body, so the accessibility of axes relies solely on characteristics of the body. Both front/back and head/feet axes have biological asymmetries, but the front/back asymmetry is more influential. The front/back axis separates the world that can be perceived and manipulated from the world that cannot be easily perceived or easily manipulated. Thus, according to the spatial framework theory, for a reclining observer, fastest times should be to the front/back axis, followed by the head/feet axis, and, last, the left/right axis. This pattern of reaction times emerged for the two reclining experiments of Franklin and Tversky (1990), and for subsequent research as well. Both the upright and reclining patterns were replicated in an experiment using objects as probes for directions (Bryant and Tversky, 1992). In all of the experiments comparing upright and reclining postures, reaction times in the reclining condition were longer than those in the upright condition. This finding fits with the premisses of the spatial framework theory. In their interactions in the world, people typically are upright as they turn and navigate.

4.6 Spatial Framework Theory: Third Person Narratives. After examining the simplest case, of an observer surrounded by objects, standing or reclining in the environment, and turning to face different objects, we began to vary the situation. In the first variation, we described the scenes in the third person rather than the second person. Thus, we have substituted an egocentric or deictic frame of reference with an object-centered or intrinsic frame of reference (e. g., Levelt, 1984; Marr and Nishihara, 1978). We expected that readers would still adopt the internal perspective of the observer in the scene, even when that observer was described as a person other than "you" (Bryant, Tversky, and Franklin, 1992). The same pattern of reaction times resulted, suggesting that subjects did in fact adopt the perspective of the third person.

We then replaced the human observer with an inanimate object that was successively turned to face different objects in the environment (Bryant, et al., 1992). We chose objects that had intrinsic fronts, backs, tops, bottoms, lefts, and rights, such as a saddle. Objects don't usually have heads and feet, but they do have tops and bottoms, if only by default. With one exception, the patterns of reaction times resembled those of the internal spatial framework, suggesting that readers take the point of view of the central object. The exception was long reaction times for top and bottom under reclining conditions. This was, we believe, a semantic problem. For objects that do not have intrinsic tops and bottoms, "top" is used to refer to the side that is currently upwards. Thus, "top" has two meanings for objects. When the object is upwards, the two meanings coincide, but when the object reclines, the intrinsic top is no longer directed upwards. This conflict seemed to have increased the time to respond top or bottom for reclining objects.

4.7 Spatial Framework Theory: External Case. Yet another case of interest is that where an array of objects is in front of the observer, rather than surrounding the observer. We examined two external settings, one consisting of eight objects in a cubic array, and the second consisting of six objects surrounding another person (Bryant, et al., 1992). The descriptions were written from the point of view of an observer external to the scene, and the queries were from that point of view as well. In these cases, "above" meant above another object or above the other person, and "below" meant the converse. "Left" and "right" meant left or right of another object or the person from the point of view of the external observer. The case of front and back is slightly more complicated. In both cases, all the objects were in front of the observer. "Front" referred to the object closer to the observer, and "back" to the one farther from the observer.

The spatial framework theory can be extended to this situation. As before, for the external case, readers construct a mental spatial framework based on three orthogonal axes, but now they are based on axes projected in front of the observer, as the array is in front of the observer, not surrounding the observer. The axes remain ordered the same as for the upright internal case, but for slightly different reasons. Above/below is most salient because of the asymmetric effect of gravity on the world. Front/back is next because it, too, is asymmetric. Objects to the front appear larger and clearer than objects to the back, and objects to the front may occlude objects to the back. Left/right is, as before, least accessible because it has no salient asymmetries. We expected one difference between internal and external patterns of reaction times. When the observer is surrounded by objects, objects to the front are more accessible than objects to the back. However, when the array is entirely in front of the observer, the difference in accessibility of front and back objects is minimal. Thus, for the internal case, we expected front to be faster than back, and for the external case, we expected no differences in reaction times to front and back. All of these predictions were obtained for both settings of the external spatial framework.

5 Small Scale Environments: Description vs. Perception.

5.1 Introduction.

The previous work has shown that the spatial framework analysis of how mental representations of space are constructed based on our conceptions of the spatial world can account for behavior in a variety of situations. All the situations were instantiated by description, not by actual experience. That is an interesting finding in and of itself, but it leaves open the question of whether memory retrieval would be the same for situations learned by actual perception rather than vicariously through description. It also leaves open another question, of importance for theories of imagery, whether responding from memory is the same as responding from perception. According to the classic view of imagery (cf. Finke and Shepard, 1986; Kosslyn, 1980), imagery is like internalized perception, so that responding from memory and responding from perception should be identical.

5.2 Responding from Memory is the same for Learning from Observation and Learning from Description.

5.2.1 Tasks. Bryant, Lanca, and I (Bryant and Tversky, 1991; Bryant, Tversky and Lanca, 1993) posed both those questions. We asked whether responding from memory is the same when scenes are learned from observation as when scenes are learned from description for both internal and external spatial framework situations. To learn the internal case by observation, subjects were brought into a small room, and stood or reclined on a bench. Objects were fastened to the walls, ceiling and floor. Subjects learned the scenes by turning and looking to see what objects were where, and were tested, as in the case of learning by description, from memory. This was repeated several times for different sets of related objects. To learn the external case by observation, subjects viewed a model scene, a 12" doll surrounded by objects. As before, they were tested from memory.

5.2.2 Results. For both internal and external situations, the pattern of responding when learning was by observation was identical to the pattern of responding when learning was by description. For the internal case, when upright, responses were fastest to head/feet, then to front/back, and last to left/right; for reclining, front/back was fastest, followed by head/feet and then left/right. For the external case, responses were fastest for head/feet, then front/back, and then left/right. For the internal case, front was faster than back, but there were no differences between front and back for the external case. Thus, performance from memory was the same, whether learning was by actually viewing a scene or by reading about a scene.

5.3 Responding from Memory is Different from Responding from Observation.

5.3.1 Memory. Here, we studied scenes that were learned by observation but tested either from memory or from observation. The task was the internal situation described above, where a subject was standing or lying on a bench, and objects were attached to the surrounding walls, ceiling and floor. The first study of responding from observation to the internal situation (Bryant and Tversky, 1991) showed that when the objects stayed in the same positions and subjects moved in the environment, subjects quickly learned the set of objects and stopped looking even when they had the opportunity. We could tell they were responding from memory because they stopped turning their heads to look. Thus, people often choose to respond from memory rather than looking to see. Apparently the effort of searching the world can be greater than the effort of searching memory. When subjects responded from memory, the pattern of reaction times fit the spatial framework pattern.

5.3.2 Observation. In the first experiment, when subjects responded while turning to look at the objects, their pattern of responses did not conform to the spatial framework pattern of data. There were too few data points in the observation condition to allow any conclusions to be drawn. In the second experiment investigating responding to the internal situation from observation (Bryant, Tversky, and Lanca, 1993), subjects were not given time to study the scene before they were probed for objects in the six directions from the body. This manipulation worked; subjects were forced to look in the probed direction before responding. When subjects responded from observation, the pattern of reaction times did not conform to the spatial framework pattern. Rather, the times conformed to what might be called the *physical transformation* model, according to which time to respond to a probe should increase with increasing time to search the scene. Specifically, times were fastest for front, next fastest for the objects displaced 90 degrees, that is head, feet, left, and right, and slowest for the object displaced 180 degrees, the object to the back.

5.4 Conclusions.

The spatial mental models formed from observing a scene seem to be the same as those formed from reading about a scene. The memory retrieval times form the same pattern, the spatial framework pattern, in both cases. As for the work on large-scale descriptions, we would like to add some caveats. We do not mean to say that descriptions are equivalent to experience or even that the mental representations of descriptions are the same as those for experience. Clearly, there are important and detectable differences between experiencing and reading and between memories of experiences and memories of descriptions. However, it is important to note that the pattern of memory retrieval of spatial relations is the same whether the spatial relations are acquired from text or from observation.

In contrast, the spatial mental models in memory are not like internalized perceptions. We expected this to happen because of the failure of the mental transformation theory to account for the original (and subsequent) patterns of data. In fact, responding from perception yields a pattern of data much like that of the mental transformation theory, only it is for physical transformation, for perceptual search rather than mental search. Mental search does not seem to be like perceptual search for this situation. Thus, people's mental representations of space are not always like their perceptions of space. For the case of keeping track of directions of objects, people's mental representations of space are better accounted for by their conceptions of space than by their perceptions of space.

6 Small Scale Environments: Two Perspectives.

6.1 Two Strategies.

6.1.1 Switching Perspectives. The studies with Bryant and Franklin (Bryant, et al., 1992) showed that readers could take the perspectives of third person characters, and even of objects, in answering questions about spatial relations. Using quite different tasks, others have shown that readers can take the perspectives of others (e. g., Bower, 1978; Bly, 1989). Franklin, Coon, and I (Franklin, Tversky, and Coon, 1992) wondered what would happen if there were more than one perspective in a scene and subjects were required to answer questions from both perspectives. There seemed to be two possibilities. The first possibility is that readers adopt each perspective as their own, switching perspectives as needed. This would result in a spatial framework pattern of data for each perspective.

6.1.2 Neutral Perspective. A second strategy readers could take would be to adopt a neutral perspective, not one of the narrative perspectives, and compute the answers to the spatial relation questions from each narrative perspective in turn. Adopting one perspective and computing the spatial relations for a different one is a more complex process for which the spatial framework pattern in not expected. Having one perspective but answering from a different one is, however, something that we frequently do in real life. When we tell someone there's a bike coming up on their left or a bee above their head, we have our own perspective but need to communicate from the other's perspective.

6.2 Determinants of Strategies.

6.2.1 Cognitive Load. What determines whether subjects adopt and switch narrative perspectives or adopt a neutral perspective and calculate the spatial relations? One factor might be the cognitive load imposed by the two strategies. In the case of taking a neutral perspective, subjects need to keep the entire scene in mind, but they do not have to switch perspectives. They have a larger memory load, but they do not have the burden of changing points of view. In the case of switching perspectives, for each perspective subjects have a smaller memory load, only those parts of a scene relevant to that perspective, but they have the cognitive burden of switching perspectives. Maintaining items in storage and performing mental operations both require working memory capacity. We do not know how these two components of working memory trade off. It might be the case that for many situations, working memory capacity for the two strategies does not differ greatly.

6.2.2 Nature of Narrative. Another determinant of whether subjects switch perspectives or maintain a constant neutral perspective and calculate is the nature of the narrative description. Where the narrative describes the two perspectives as part of the same scene, say, the scene from the perspectives of two characters, then the reader may adopt a neutral perspective that allows inclusion of the entire scene, including both characters' perspectives. If, on the other hand, the narrative describes two different scenes, each with a single perspective, the reader may form a separate representation for each scene, and, as in the previous research, adopt the character's perspective for each one, switching perspectives as the scenes switch.

6.3 Experiments and Conclusions.

Franklin, Coon and I (Franklin, et al., 1992) wrote narratives containing two perspectives in a variety of situations. For situations where there were two characters in the same place, readers did not take the two perspectives in alternation; rather, they took a neutral point of view. This was the case even when one of the characters was foregrounded in the narratives, when that character was referred to as "you" and the other character in the third person, and when there were three times as many questions from one character's perspective as from the other's. A neutral perspective was also adopted for narratives describing "you" in the same place at two different times oriented in different ways, as in a flashback situation. The only case we have found so far where readers take the perspectives of each of the characters in turn is when the narratives describe the characters as being in different places, say, one underwater in a lagoon, and another in a hotel lobby. Then the spatial framework pattern of retrieval times emerges for both settings.

Readers are able to adopt both strategies, taking a neutral perspective and computing both character perspectives, and taking character perspectives in turn. Readers adopt the strategy that conforms best to the narrative. These findings led us to the *one place-one perspective principle*. Readers seem to prefer to form a separate mental representation for each place described in a narrative, and to take a single perspective for each place. If the place contains a single perspective, then readers take that perspective. If, however, the place has two perspectives, either because there are two characters with different perspectives or the same character at different times with different perspectives, then the reader adopts a single perspective, but takes a neutral perspective rather than any of the perspectives in the scene.

7 Small Scale Environments: Moving Observer vs. Moving Environment.

Thus far, all the narratives have described an observer moving in an environment. It is also conceivable, especially in a narrative, for the observer to remain stationary, and the environment to move. Although the moving environment situation can be formally equivalent to the moving observer situation, psychologically the two situations are quite different. In the real world, people typically move and environments are typically stationary. If people's conceptions of the spatial world are based, as the spatial framework theory asserts, on typical interactions with the spatial world, then it should be easier for readers to perform the moving observer situation than the moving environment situation. If all that matters is the bare mental model, then the two situations should be equally easy.

7.1 Movement in Three Planes.

Two senior honors students, Joe Kim and Andrew Cohen, worked on this problem. Kim wrote a set of narratives telling subjects that they were visiting a gravity-free spacehouse in a NASA museum where objects were bolted to the surfaces. The subjects in the moving observer condition were told that in the weightless environment, they could reorient themselves along the three axes. The subjects in the moving environment condition were told that the rooms could rotate along the three axes. The experiment then proceeded much like the usual internal spatial framework experiments, testing upright, reclining, and upside-down postures (relative to the original posture; there were no absolute directions in the gravity-free spacehouse). The subjects in the moving observer condition had no difficulty performing the experiment, and the data conformed to the spatial framework pattern. In contrast, the subjects in the moving environment condition simply could not perform the task. After several reorientations, they became confused, and could not keep track of where the observer was relative to the objects. This was despite the fact that many of the subjects realized that the moving environment situation was formally equivalent to the moving observer situation.

7.2 Movement in the Horizontal Plane.

Kim's second experiment simplified the situation considerably by using only horizontal reorientations. The horizontal plane was easier than the vertical in the previous studies where only the observer moved, presumably because most human navigation is along the horizontal plane. Perhaps giving considerable practice along the easier, more familiar, plane will enable readers to cope with the moving environment situation. Kim took two reaction time measures: the time it took to reorient to a facing a new object, and, after reorientation, the time it took to retrieve objects given direction probes.

When movement was only along the horizontal plane, subjects in both the moving observer and the moving room conditions were able to perform the task. Subjects in the moving room condition found the task harder. It took them nearly twice as much time to reorient along the horizontal plane as the moving observer subjects. Once they had reoriented, the moving room subjects answered the direction probes as fast as the moving observer subjects. In both cases, the reaction times conformed to the spatial framework pattern.

7.3 Vertical Movement along a Single Plane.

Encouraged by the success of Kim's second experiment, Cohen designed situations slightly more complex than the second study, but less complex than Kim's first study. In Kim's first study, vertical and horizontal movements were randomly mixed. In Cohen's study, all the vertical movements were blocked and all the horizontal movements were blocked. As before, there were two groups of subjects; for one, the narratives described the observer as moving, and for the other, the narratives described the environment as moving.

Subjects in both the moving observer and moving environment conditions were able to perform the task. Those in the moving environment condition took longer to respond to the direction probes than those in the moving observer condition. The data of subjects in the moving observer condition corresponded to the spatial framework pattern. The data of subjects in the moving environment condition corresponded to the spatial framework pattern for the original orientation of the room, and for the upside down orientation, but not when the room was rotated 90 degrees. When the room moves from upright to upside down, the objects at the head/feet and front/back stay the same, but their positions get reversed. The objects along the right/left axis stay the same. When room is rotated 90 degrees, the objects to right and left stay the same, but the objects at head and feet get mapped onto front and back, and vice versa. The mental transformation required for 90 degree rotation, remapping the axes, is more difficult than the mental transformation required for upside down, reversing the objects along the same axes. For the 90 degree rotation, it seems that subjects kept the perspective of the original upright position and computed the new positions of the objects. Because the objects at left and right did not change, these were the fastest. Front/back and head/feet were equally slow, as they were remapped onto each other.

7.4 In Sum.

Although it is much more difficult for readers to perform when narratives describe the environment as moving than when narratives describe the observer as moving, under certain circumstances, readers are able to perform the task. When movement is along the horizontal plane, they can perform the task, but take longer to reorient in the moving environment condition. When movement is only along one vertical plane and sufficient practice is given, readers are able to perform in the moving environment task even in the relatively unfamiliar vertical plane, though readers are faster to respond to direction probes in the moving observer condition than in the moving environment condition. Moreover, readers take all three perspectives in the moving observer condition, upright (original), reclining, and upside down, but they do not take all perspectives in the moving environment condition. For the analog of the reclining case, readers in the moving room condition seem to maintain their original perspective and compute the spatial relations. It is possible that with more practice in this orientation, readers will take that perspective as well.

The moving observer and moving environment conditions are formally identical. Psychologically, though, the former corresponds to everyday experience and the latter does not. Readers could perform under some circumstances in the moving environment condition, but only with difficulty.

8 Conclusions.

8.1 Spatial Descriptions Engender Spatial Mental Models.

Well-crafted descriptions can successfully convey spatial relations for both large scale and small scale environments. From such descriptions, readers seem to form spatial mental models that incorporate the spatial relations among landmarks. These spatial mental models vary in abstractness: general ones capture the spatial relations among landmarks in a perspective-free fashion; from the general models, models with specific perspectives can be derived. The spatial mental models can be updated as new information comes in. Updating can take many forms: adding landmarks, moving, reorienting, changing perspectives, and more.

8.2 Route and Survey Descriptions of Large Scale Environments.

For describing large scale environments, people use one of two perspectives, or a combination of both. In route descriptions, describers take their addressees on a mental tour of an environment, conveying the locations of landmarks relative to the changing position of the addressee in terms of the addressee's left, right, front, and back. In survey descriptions, describers take a view from above, conveying the locations of landmarks relative to each other in terms of north, south, east, and west. From either type of description, readers can form spatial mental models that allow taking both perspectives, route or egocentric or deictic, and survey or extrinsic. Because interfaces with GIS systems are typically verbal, understanding how people construct and comprehend spatial descriptions is fundamental to effective GIS systems.

8.3 Spatial Frameworks for Small Scale Environments.

For keeping track of small scale environments, the objects immediately surrounding them, people construct and update mental spatial frameworks from three orthogonal axes defined by the body, head/feet, front/back, left/right. The time to retrieve objects located in those directions from the body depends systematically on enduring characteristics of people's interactions with the perceptual world. For the canonical upright situation, the head/feet axis is most accessible because it is an asymmetric axis of the body and because it is aligned with gravity, the only asymmetric axis of the world. Front/back is next; its asymmetry divides the world that can be perceived and manipulated from the world that cannot be easily perceived and manipulated. The front/back axis is also the normal plane of navigation. Finally, the left/right axis has no salient asymmetries. This *spatial framework analysis* accounted for memory retrieval times in the canonical case, and variations in the spatial framework analysis accounted for retrieval times in variants of it. Unlike images, spatial frameworks are not like internalized perceptions; rather than reflecting people's perceptions of the world, they reflect people's conceptions of the world.

8.4 Further Explorations of Small Scale Environments.

8.4.1 Two Perspectives. When a narrative has a single perspective, readers tend to adopt that perspective as their own. When a narrative has more than one perspective, readers do one of two things. They either adopt both perspectives as their own and switch between them, or they take a neutral perspective that is not one of the narrative perspectives, and calculate the directions of objects from the narrative perspectives as needed. When the two perspectives are in different scenes, subjects tend to switch perspectives; when the two perspectives are in the same setting, subjects tend to adopt a neutral perspective. Both strategies are available to people. People seem to prefer to take a single perspective on a single scene.

These studies have begun to explore perspective taking and perspective switching in naturalistic contexts. When we use a map or a GIS system to plan a route or figure out where we are, we need to be aware of our own perspective, but to take or calculate another one as well.

8.4.2 Moving Person vs. Moving Environment. In narrative, it is just as easy to have the environment move as to have the person move in the environment. When the movements are rotations along one of the body planes, the two are formally equivalent. Moving rooms are not a normal part of people's interactions with the world, so the spatial framework analysis predicts that the moving room situation would be more difficult than the moving person. Subjects indeed find the moving room situation more difficult than the moving person. For descriptions involving movements along both vertical and horizontal planes, subjects had no trouble in the moving person condition, but were unable to perform the moving room condition. When the moving room condition was simplified to movement along only the horizontal plane, or to more systematic and practiced movement along both planes, subjects could cope with the moving room situation, but took longer to respond than in the moving person situation.

8.5 Final Words. Language can have powerful effects on our lives. One common and benign use of language is to describe space. The language of space is rich and organized. Under ideal circumstances, language can instill accurate mental representations of the spatial relations among objects in a scene. The effectiveness of language in engendering spatial mental representations provides a convenient way to study the construction, use, updating, and nature of spatial mental representations. The language of space not only instills mental representations, it also reveals how people think about space.

References

Abelson, R. (1975). Does a story understander need a point of view? in R. Schank and B. L. Nash-Webber (Eds.), *Theoretical issues in natural language processing*. Washington, D. C.: Association for Computational Linguistics.

Anderson, R. C. and Pichert, J. W. (1978). Recall of previously unrecallable information following a shift in perspective. *Journal of Verbal Learning and Verbal Behavior, 17,* 1-12.

Bly, B. (1989). Perspective in mental models of text. Unpublished manuscript, Stanford University.

Bower, G. H. (1978). Experiments on story comprehension and recall. *Discourse Processes, 1,* 211-231.

Bryant, D. J. and Tversky, B. (1991). Locating objects from memory or from sight. Paper presented at 32nd Annual Meeting of the Psychonomic Society, San Francisco.

Bryant, D. J. and Tversky, B. (1992). Assessing spatial frameworks with object and direction probes. *Bulletin of the Psychonomic Society, 30,* 29-32.

Bryant, D. J., Tversky, B, and Lanca, M. (1993). Retrieving spatial relations from observed and remembered scenes. Manuscript submitted for publication.

Bryant, D. J., Tversky, B., & Franklin, N. (1992). Internal and external spatial frameworks for representing described scenes. *Journal of Language and Memory, 31,* 74-98.

Clark, H. H. (1973). Space, time, semantics and the child. In T. E. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 27-63). N. Y.: Academic Press.

Ehrlich, K. & Johnson-Laird, P. N. (1982). Spatial descriptions and referential continuity. *Journal of Verbal Learning and Verbal Behavior, 21,* 296-306.

Ehrich, V. & Koster, C. (1983). Discourse organization and sentence form: The structure of room descriptions in Dutch. *Discourse Processes,* 6, 169-195.

Evans, G. W. & Pezdek, K. (1980). Cognitive mapping: Knowledge of real-world distance and location information. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 13-24.

Fillmore, C. J. (1975). *Santa Cruz lectures on deixis.* Bloomington, IN: Indiana University Linguistics Club.

Finke, R. A., & Shepard, R. N. (1986) Visual functions of mental imagery. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance.* N. Y.: Wiley.

Franklin, N. & Tversky, B. (1990). Searching imagined environments. *Journal of Experimental Psychology: General, 119,*

Franklin, N., Tversky, B., and Coon, V. (1992). Switching points of view in spatial mental models acquired from text. *Memory and Cognition, 20,* 507-518.

Glenberg, A. M., Meyer, M., & Lindem, K. (1987). Mental models contribute to foregrounding during text comprehension. *Journal of Memory and Language, 26,* 69-83.

Johnson-Laird, P. N. (1983). *Mental models.* Cambridge, Mass: Harvard.

Kosslyn, S. M. (1980). *Image and mind.* Cambridge, MA: Harvard University Press.

Levelt, W. J. M. (1982). Linearization in describing spatial networks. In S. Peters and E. Saarinen (Eds.) *Processes, beliefs, and questions.* Pp. 199-220. Dordrecht: Reidel.

Levelt, W. J. M. (1984). Some perceptual limitations on talking about space. In A. J. van Doorn, W. A. de Grind, & J. J. Koenderink (Eds.), *Limits in perception.* Utrecht, The Netherlands: VNU Science Press.

Linde, C., & Labov, W. (1975). Spatial structures as a site for the study of language and thought. *Language, 51,* 924-939.

Mani, K., & Johnson-Laird, P. N. (1982). The mental representation of spatial descriptions. *Memory and Cognition, 10,* 181-187.

Marr, D. and Nishihara, H. K. (1978). Representation and recognition of the spatial organization of three-dimensional shapes. *Proceedings of the Royal Society B, 200,* 269-291.

Miller, G. A. & Johnson-Laird, P. N. (1976). *Language and perception*. Cambridge: Harvard.

Morrow, D. G., Bower, G. H., & Greenspan, S. (1989). Updating situation models during narrative comprehension. *Journal of Memory and Language, 28*, 292-312.

Morrow, D. G., Greenspan, S., & Bower, G. H. (1987). Accessibility and situation models in narrative comprehension. *Journal of Memory and Language, 26*, 165-187.

Perrig, W., & Kintsch, W. (1985). Propositional and situational representations of text. *Journal of Memory and Language, 24*, 503-518.

Schiano, D. and Tversky, B. (1992). Structure and strategy in viewing simple graphs. *Memory and Cognition, 20*, 12-20.

Shepard, R. N. & Hurwitz, S. (1984). Upward direction, mental rotation, and discrimination of left and right turns in maps. *Cognition, 18*, 161-194.

Sholl, M. J. (1987). Cognitive maps as orienting schemata. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13*, 615-628.

Streeter, L. A., Vitello, D. & Wonsiewicz, S. A. (1985). How to tell people where to go: Comparing navigational aids. *International Journal of Man-Machine Studies, 22*, 549-562.

Taylor, H. A. and Tversky, B. (1992a). Descriptions and depictions of environments. *Memory and Cognition, 20*, 483-496.

Taylor, H. A. and Tversky, B. (1992b). Spatial mental models derived from survey and route descriptions. *Journal of Memory and Language, 31*, 261-282.

Taylor, H. A. and Tversky, B. (1993). Perspective in spatial descriptions. Manuscript submitted for publication.

Tversky, B. (1991a). Distortions in memory for visual displays. In S. R. Ellis (Ed.) and M. K. Kaiser and A. Grunwald (Associate Editors), *Pictorial communication in virtual and real environments* (pp. 61-75). London: Taylor and Francis.

Tversky, B. (1991b) Spatial mental models. In G. H. Bower (Ed.), *The*

Psychology of Learning and Motivation: Advances in Research and Theory. Vol. 27 (pp. 109-145). N. Y.: Academic Press.

Tversky, B. (1992a). Distortions in cognitive maps. *Geoforum, 23,* 131-138.

Tversky, B. (1992b). Spatial mental representations. In N. H. Narayanan (Ed.), *Reasoning with diagrammatic representations*. Proceedings of the 1992 AAAI Spring Conference. Menlo Park, CA: AAAI.

Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In A. U. Frank and I. Campari (Editors), *Spatial information theory: A theoretical basis for GIS*. Pp. 14-24. Berlin: Springer-Verlag.

Tversky, B. (In press, a). Cognitive origins of graphic conventions. In F. T. Marchese (Editor). *Understanding images*. New York: Springer-Verlag.

Tversky, B. (In press, b). Spatial constructions. In N. Stein, C. Brainerd, P. Ornstein, and B. Tversky (Eds.) *Memory for emotion and everyday events*. Hillsdale, NJ: Erlbaum.

Tversky, B. (In press, c). Speculations on cognitive origins of graphic conventions. In G. Ben Shakhar and A. Lieblich (Editors), *Studies in psychology: In honor of S. Kugelmass*. Jerusalem: Magnes Press.

Tversky, B. and Clark, H. H. (1993). Prepositions aren't places. *Brain and Behavioral Sciences, 16:2,* 252-253.

Tversky, B., Kugelmass, S. and Winter, A. (1991) Cross-cultural and developmental trends in graphic productions. *Cognitive Psychology, 23,* 515-557.

Thorndyke, P. W. (1981). Spatial cognition and reasoning. In J. Harvey (Ed.), *Cognition, social behavior, and the environment*. Hillsdale, NJ: Erlbaum.

Thorndyke, P. W. & Hayes-Roth, B. (1982). Differences in spatial knowledge acquired from maps and navigation. *Cognitive Psychology, 14,* 560-589.

Ullmer-Ehrich, V. (1982). The structure of living space descriptions. In R. J. Jarvella and W. Klein (Eds.), *Speech, place and action*. Pp. 219-249. N. Y.: Wiley.

Professional Personnel. the following professionals have participated in the research: Dr. Nancy Franklin, former graduate student, currently Assistant Professor at State University of New York, Stony Brook; Dr. Diane Schiano, former post-doctoral student, now at Interval Research; Dr. David J. Bryant, former graduate student, now Assistant Professor at Northeastern University; Dr. Holly Taylor, former graduate student, now Assistant Professor at Texas Christian University; Dr. Caren M. Jones, former graduate student, now Assistant Professor at University of Massachusetts, Amherst; Dr. Kathy Hemenway, former graduate student, now at Sun Microsystems; Professor Herbert H. Clark, colleague at Stanford University; Proessor Sol Kugelmass at Hebrew University, Jerusalem; Scott Mainwaring, Atalia Winter, Deborah Tatar, and Laura Miller, graduate students; Joseph Kim, Jay Leahy, and Andrew Cohen, undergraduate Honors students; about a dozen other undergraduates.

Dissertations. Nancy Franklin received her Ph. D. in September, 1989; her thesis was entitled, "Constraints on Memory Search Imposed by Spatial Features of Described Scenes." David J. Bryant received his Ph. D. in July, 1991; his thesis was entitled, "Perceptual Characteristics of Mental Spatial Models." Holly A. Taylor received her Ph. D. in September, 1992; her thesis was entitled, "Who did what when? Memory Organization of Event Descriptions." Caren M. Jones received her Ph. D. in September, 1992; her dissertation was entitled, "construction of a Mental Model from Objects, Features, and Locations."

Grant-related publications.

Bryant, D. J. and Tversky, B. (1992). Assessing spatial frameworks with object and direction probes. *Bulletin of the Psychonomic Society, 30,* 29-32.

Bryant, D. J., Tversky, B., & Franklin, N. (1992). Internal and external spatial frameworks for representing described scenes. *Journal of Language and Memory, 31,* 74-98.

Bryant, D. J., Tversky, B., and Lanca, M. (1993). Spatial mental models from observed and remembered scenes. Manuscript submitted for publication.

Franklin, N. and Tversky, B. (1990). Searching imagined environments. *Journal of Experimental Psychology: General, 119,* 63-76.

Franklin, N., Tversky, B., and Coon, V. (1992). Switching points of view in spatial mental models acquired from text. *Memory and Cognition, 20,* 507-518.

Schiano, D. and Tversky, B. (1992). Structure and strategy in viewing simple graphs. *Memory and Cognition, 20,* 12-20.

Taylor, H. A. and Tversky, B. (1992). Spatial mental models derived from survey and route descriptions. *Journal of Memory and Language, 31,* 261-282.

Taylor, H. A. and Tversky, B. (1992). Descriptions and depictions of environments. *Memory and Cognition, 20,* 483-496.

Taylor, H. A. and Tversky, B. (1993). Perspective in spatial descriptions. Manuscript submitted for publication.

Taylor, H. A. and Tversky, B. (1993). Character and time as organizers of events in memory. Manuscript submitted for publication.

Tversky, B. (1990). Where partonomies and taxonomies meet. In S. L. Tsohatzidis (Ed.), *Meanings and prototypes: Studies on linguistic categorization* (pp. 334-344). London: Routledge.

Tversky, B. (1991). Distortions in memory for visual displays. In S. R. Ellis (Ed.) and M. K. Kaiser and A. Grunwald (Associate Editors), *Pictorial communication in virtual and real environments* (pp. 61-75). London: Taylor and Francis.

Tversky, B. (1991) Spatial mental models. In G. H. Bower (Ed.), *The Psychology of Learning and Motivation: Advances in Research and Theory*. Vol. 27 (pp. 109-145). N. Y.: Academic Press.

Tversky, B. (1992). Spatial mental representations. In N. H. Narayanan (Ed.), *Reasoning with diagrammatic representations*. Proceedings of the 1992 AAAI Spring Conference. Menlo Park, CA: AAAI.

Tversky, B. (1992). Distortions in cognitive maps. *Geoforum, 23,* 131-138.

Tversky, B. (1992). Images before and behind the eye. Review of *Images and Understanding*, edited by H. Barlow, C. Blakemore and M. Weston-Smith. *Contemporary Psychology, 37,* 931-932.

Tversky, B. (1993). Cognitive maps, cognitive collages, and spatial mental models. In A. U. Frank and I. Campari (Editors), *Spatial information theory: A theoretical basis for GIS*. Pp. 14-24. Berlin: Springer-Verlag.

Tversky, B. (1993). Some challenges for a computational account of imagery. *Computational Intelligence,* , - .

Tversky, B. (In press). Spatial constructions. In N. Stein, C. Brainerd, P. Ornstein, and B. Tversky (Eds.) *Memory for emotion and everyday events*. Hillsdale, NJ: Erlbaum.

Tversky, B. (In press). Cognitive origins of graphic conventions. In F. T. Marchese (Editor). *Understanding images*. New York: Springer-Verlag.

Tversky, B. (In press). Speculations on cognitive origins of graphic conventions. In G. Ben Shakhar and A. Lieblich (Editors), *Studies in psychology: In honor of S. Kugelmass. Jerusalem: Magnes Press.*

Tversky, B. and Clark, H. H. (1993). Prepositions aren't places. Brain and Behavioral Sciences, 16:2, 252-253.

Tversky, B., Franklin, N., Taylor, H. A., and Bryant, D. J. (Submitted). Spatial mental models from descriptions. *Journal of the American Society for Information Science.*

Tversky, B. and Hemenway, K. (1991). Parts and the basic level in natural categories and artificial stimuli: Comments on Murphy (1991). *Memory and Cognition, 19,* 439-442.

Tversky, B., Kugelmass, S. and Winter, A. (1991) Cross-cultural and developmental trends in graphic productions. *Cognitive Psychology, 23,* 515-557.

Tversky, B. and Schiano, D. (1989). Perceptual and conceptual factors in distortions in memory for maps and graphs. *Journal of Experimental Psychology: General, 118,* 387-398. *Spatial and temporal reasoning.*

Tversky, B. and Taylor, H. A. (In press). Acquiring spatial and temporal knowledge from language. In M. J. Egenhofer and R. G. Golledge (Editors),

Papers presented at meetings, conferences, and colloquia:

"Cognitive Maps" presented at the Air Force Office of Scientific Research, November, 1988.

"Answering Questions about Imagined Scenes: How Do We Look?" with Nancy Franklin, presented at the 29th Annual Meeting of the Psychonomic Society, Chicago, November, 1988.

"Spatial Mental Models Induced by Narratives" presented at Columbia University Psychology Department, September, 1989.

"Induced Pictorial Representations" presented to AFOSR meeting, Alexandria, VA, November, 1989.

"Learning Environments from Survey and Route Descriptions" with Holly A. Taylor, poster presented at the 30th Annual Meeting of the Psychonomic Society, Atlanta, November, 1989.

"Structure and Strategy in Memory for Line Slope" with Diane Schiano, poster presented at the 30th Annual Meeting of the Psychonomic Society, Atlanta, November, 1989.

"Spatial Mental Models" Cognitive Science Seminar presented at Princeton University, April, 1990.

"Spatial Mental Models" presented at the Center for the Study of Language and Information, Stanford University, May, 1990.

"General Organizational Principles for Characterizing Observers' Perspectives in Described Scenes." with David Bryant and Nancy Franklin, poster presented at the American Association for the Study of Mental Imagery, Boston, June, 1990.

"Different Memory Representations for Space Surrounding You, Him, and It?" with David Bryant and Nancy Franklin, poster presented at the annual meetings of the American Psychological Association, Boston, August, 1990.

"Constructing, Updating, and Accessing a Representation of Described Space," by Nancy Franklin, poster presented at the annual meetings of the American Psychological Association, Boston, August, 1990.

"The Spatial Organization of Mental Models" by Nancy Franklin, colloquium presented at New York University, October, 1990.

"Spatial Descriptions and Depictions" with Holly A. Taylor, presented at the 31st Annual Meeting of the Psychonomic Society, New Orleans, November, 1990.

"Mental Spatial Frameworks for Different Perspectives" with Nancy Franklin, poster presented at the 31st Annual Meeting of the Psychonomic Society, New Orleans, November, 1990.

"Spatial Mental Models" presented at the Winter Text Conference, Jackson Hole, January, 1991.

"Spatial Mental Models," colloquium presented at Pomona College, February, 1991.

"Distortions in Cognitive Maps," invited lecture at Whitman College, March, 1991.

"Images, Perceptions, and Mental Models," invited lecture at the Center for the Study of Language and Information, Stanford University, April, 1991.

"Spatial Mental Models Derived from Survey and Route Descriptions" with Holly A. Taylor, poster presented at Western Psychological Association meetings, April, 1991.

"Mental Spatial Frameworks: Perspective and Organization" with David J. Bryant and Nancy Franklin, poster presented at Western Psychological Association meetings, April, 1991.

"Spatial Mental Models" with Holly A. Taylor, invited symposium at Midwestern Psychological Association, May, 1991.

"Perspective in Spatial Mental Models Derived from Text" with Nancy Franklin and Vicki Coon, invited symposium at Midwestern Psychological Association, May, 1991.

"Spatial Mental Models" invited lecture, Department of Psychology, University of California, Berkeley, October, 1991.

"Spatial Mental Models" invited colloquium, Cognitive Science Program, Wellesley College, October, 1991.

"Locating Objects from Memory or from Sight" with David J. Bryant, paper presented at 32nd Annual Meeting of the Psychonomic Society, San Francisco, November, 1991.

"Spatial Mental Representations: Are they like Images?" Invited lecture at Winter Text Conference, Jackson Hole, WY, January, 1992.

"Spatial Mental Representations" invited lecture at AAAI Spring Conference, Stanford, CA, March, 1992.

"Spatial Mental Models" invited lecture at New York University, April, 1992.

"How People think about Space" invited lecture at CSLI-IAP meetings, Tokyo, Japan, September, 1992

"Cognitive Maps," invited lecture at Tokyo Institute of Technology, Tokyo, Japan, September, 1992.

"Spatial Mental Models," invited colloquium at the Center for the Study of Language and Information, Stanford University, October, 1992.

"Spatial Mental Models," invited colloquium at University of California-Santa Cruz, October, 1992.

"Who, what, when, and where? Memory organization of event descriptions" with Holly A. Taylor. Poster presented at 33rd Annual Meeting of the Psychonomic Society, St. Louis, November, 1992.

"Cognitive Origins of Graphic Conventions" Invited lecture at Winter Text Conference, Jackson Hole, WY, January, 1993.

"Spatial Mental Models Constructed from Text." Invited talk at Workshop on Mental Models, Bielefeld, Germany, April, 1993.

"Acquiring and Updating Spatial Knowledge from Language" Invited talk at specialist meeting of NCGIA on Time in Geographic Space, Lake Arrowhead, CA, May, 1993.

"Spatial Constructions." Invited talk at Conference on Memory for Emotion and Everyday Events. University of Chicago, May, 1993

"Speculations on the Origins of Graphic Conventions." Invited talk at NYC-SIGGRAPH. Pace University, May, 1993.

"Cognitive Maps, Cognitive Collages, and Spatial Mental Models." Invited talk at European Conference on Spatial Information Theory, Elba, Italy, September, 1993.

"Spatial Mental Models Constructed from Text." Invited talk at Conference on Memory, Rome, Italy, September, 1993.

"Why is space complex? Relational versus absolute spatial descriptions," with C. M. Jones. Poster presented at the 34th Annual Meeting of the Psychonomic Society, Washington DC, 1993.

"Perspective in Spatial Descriptions," with H. A. Taylor. Poster presented at the 34th Annual Meeting of the Psychonomic Society, Washington DC, 1993.

"Mental spatial models guide search of observed spatial arrays, with D. J. Bryant, M. Lanca, and B. Narashimhan. Poster presented at the 34th Annual Meeting of the Psychonomic Society, Washington DC, 1993.